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DESIGN STUDY OF A 750 kV ELECTRON GUN FOR ELECTRON COOLING

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Introduction

A computer modeling study using the SLAC gun design code EGUN as modified here at Fermilab was performed to study the feasibility of constructing a 750 kilovolt electron beam source. The gun characteristics assumed here were a flat cathode, 2 inches in diameter, capable of supplying as much as 10 amperes of beam in a Pierce geometry with cylindrical symmetry immersed in a uniform longitudinal magnetic field.

The design guidelines were to provide a quiet beam, with an edge transverse temperature less than 1 ev before resonant tuning, over the full range of beam currents (0-10 amps).

Resonant tuning, either by an electric or magnetic lens section was to be performed at the ground plane, after the beam was fully accelerated. The tuning function would presumably lower the transverse temp. to the level of 0.1-0.2 ev.

Modularity

The overall layout of the gun structure attempts to allow convenient removal of the cathode and anode assemblies as modules so the gun can be flexible in repair and modification.

This feature utilizes a commercial ceramic column design. By implication the anode structure has an axial length of ~3 inches, where the interface flanging is located, before the accelerating column. Figure 1 shows the computer graphics depicting the gun structure used to solve Poisson's equations for the E-fields, including space charge. Trajectory calculations take into account both electric and magnetic field configuration.

Gun Optics

European e-gun design (CERN, Novosibirsk) has employed multielectrode anodes to shape the defocusing anode lens (1.) length to match the gyro-wavelength, thus achieving low transverse beam temperatures. However, the existence of the accelerating column for high energy beams introduces two more

E-lenses. Both lenses much be optimized in the optics to ensure a quiet beam.

Table I is a list of gun parameters used in the present study.

Table I. <u>Electron Source Parameters</u>

Cathode Diam. 2 inches	Column Length - 20"
Pierce el. diam. 5 inches	Column I.D. - 3.25"
Anode aperture 2.6 inches	Column electode spacing - 1/2"
Accel. Gradient 40 kV/inch.	
Anode voltage 35 kV for 10 amps	
Emission Control - 2 guard rings (G1,G2)	

Anode spacing was set for a high (1.5 microperv.) gun perveyance to achieve low anode voltage. This enables the beam to travel through the anode-column E-lens doublet, figure 4, in the adiabatic mode, taking several gyro-wavelengths to traverse this disturbance. However, high perveance guns suffer from anode destruction of the Pierce region near the cathode. In an immersed magnetic field this effect is small in temperature effects. However, non-uniform emission from the cathode surface can occur. For this reason 2 guard electrodes, (G1, G2) are used to tune the near cathode fields so that uniform emission does occur. Figure 2 shows the variation of beam uniformity vs. the G1 voltage tune.

<u>Guide Field</u>

The magnetic guide field range assumed in this study was 1000-1500 gauss. For a 750 kV beam this corresponds to a gyro-wavelength region of 7.14 to 9.53 inches. In the gun anode region this produces wavelengths of 1.0-1.5 inches so that both the anode and column entrance lens lengths are in the adiabatic region. This fact allows the gun to be run over the full current range with little effect on the beam temperature.

While the rather long full-energy gyro-wavelength (7-9 inches) has implications for the beam transport system, in particular the resonant heating from disturbances in the magnetic field at these wavelengths, one can utilize this fact to our advantage, eg. in magnetic resonant focusing.

Column Exit Lens

The accelerating column exit lens can be optimized to provide negligible transverse heating, to the emerging 750 kV beam. Figure 3 shows the effect of adjusting the column exit gradients to increase the E-lens length to about 9 inches, the typical gyro-wavelength. Without this adjustment untuned beam temperatures of about 10-20 ev were predicted.

General Results

Figure 1 shows a modeled beam trajectory set of the electron flow from a 10 amp x 750 kV source. The first section shows the gun interface to the accelerating column. The second section shows the remainder of the column and a proposed 3 electrode resonant focusing section downstream of the accelerating column.

Figure 5 (a) and (b) show the history of the beam edge transverse temperature, plotted on a transverse velocity plot, showing both radial and azimuthal velocity components. Each cross is a 0.1 inch step along the beam axis. Velocities are plotted as v_r/c, v_ϕ/c, so that 2×10^{-3} corresponds to about 1 ev of transverse temperature.

General results of various running modes are shown in Table 2. The transverse temperatures are for a 750 kV beam edge particle, with the resonant tuning section turned off. Temperatures are for the cyclotron motion only. The magnetron motion induced by the beam space charge is <0.2 ev in all cases.

Table 2. 750 kV Beam Transverse Temperatures without Resonant Focusing

Magnetic Field (gauss)	Anode Volts kV	Beam Current	T_1 (ev) (cyclotron)
1500	30	7.8 amp	0.1 ev
1000	30	7.8	0.5
1000	15	2.8	0.5
1000	35	10.0	1.0

Resonant Focusing

The second section of the modeling graphics shows a 3-electrode resonant focusing section downstream of the accelerating column. This is a convenient area for this function, situated at the ground plane. However, magnetic focusing has been modeled previously (2) and found to be successful. Solenoidal bump coils of about 10 inch diameter would match the cyclotron wavelength range discussed here and provide strong cancellation of coherent cyclotron motion to levels below 0.1 ev if required.

Low Energy Option

Computer runs of the modeled system indicated that the induced cyclotron motion caused by the gun-column interface lenses were low, as indicated by Table 3. This fact implies that such a design could be used for lower energy systems, down to about 200 kV, since the column ground plane lens could be optimized by gradient adjustment, as performed for the 750 kV case here, optimized for the lower beam energy cyclotron wavelength.

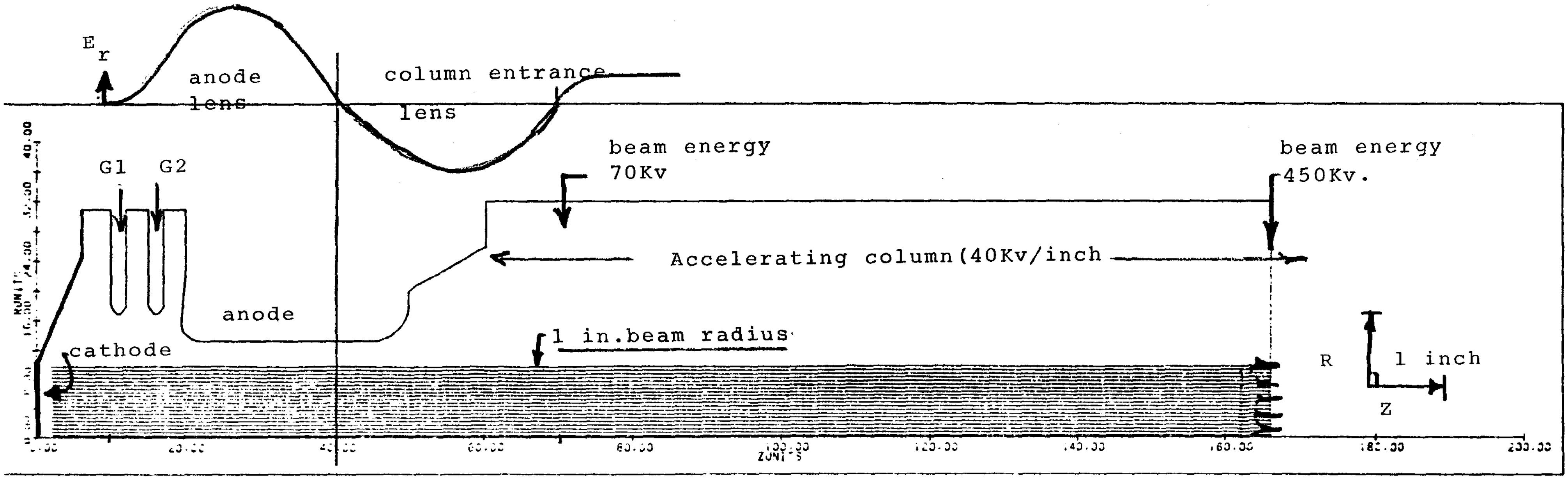
Table 3. Transverse Temp. from Gun-Column Interface (cyclotron motion)

Mag. Field Gauss	Beam Current	T_1 (ev) at 250 kV
1500	7.8 amp	0.1 ev
1000	7.8	0.6
1000	2.8	0.2
1000	10.0	1.8

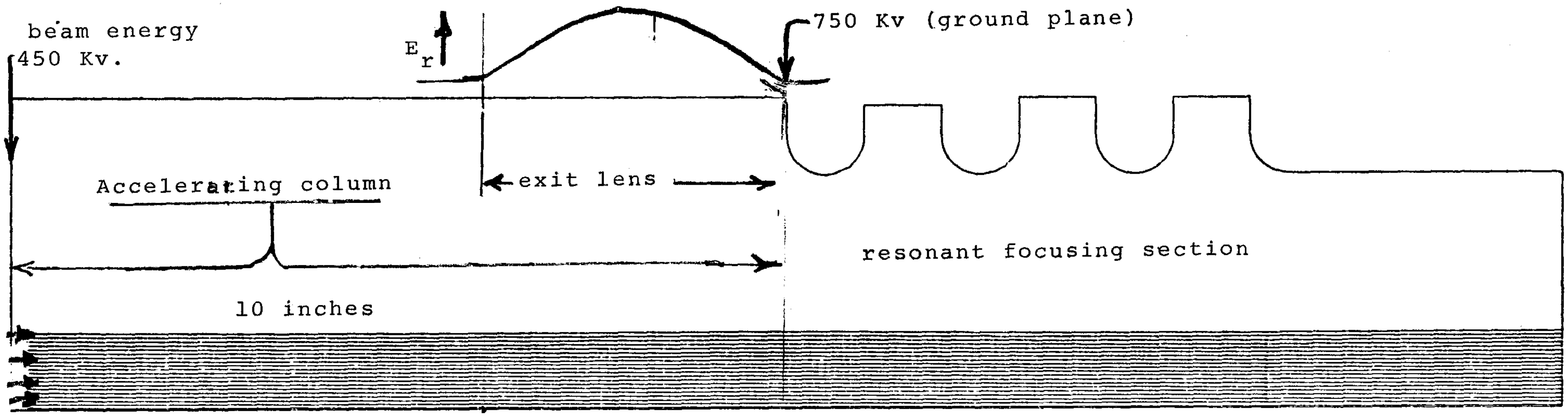
References

1. CERN report: CERN 77-08, April 1977.
2. Fermilab technical memo: TM-1004, L. Oleksiuk, October 1980.

List of Figures



Section I. Electron gun and column interface



Section II. Acc. Column and resonant focusing section.

Figure 1.

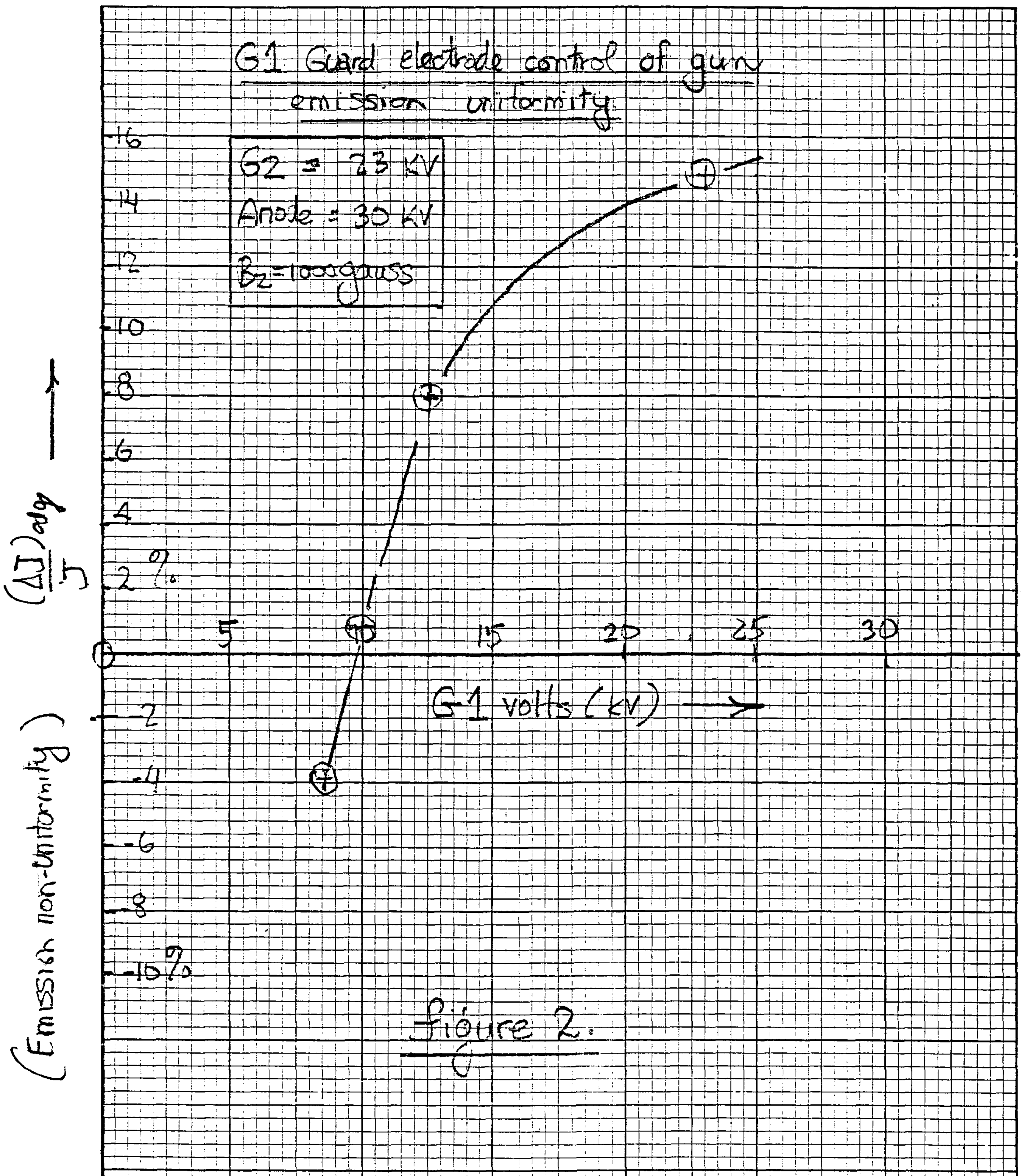
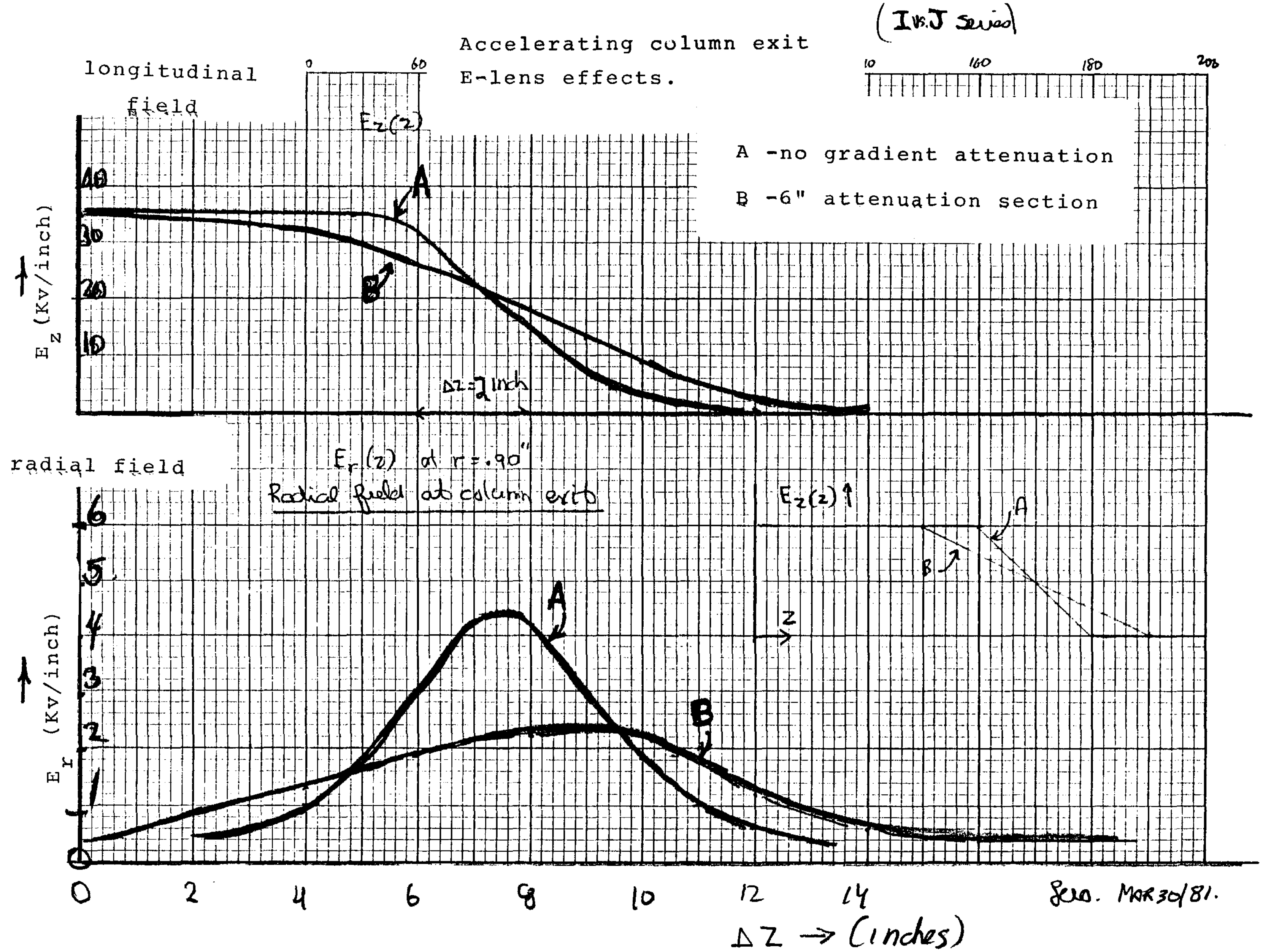
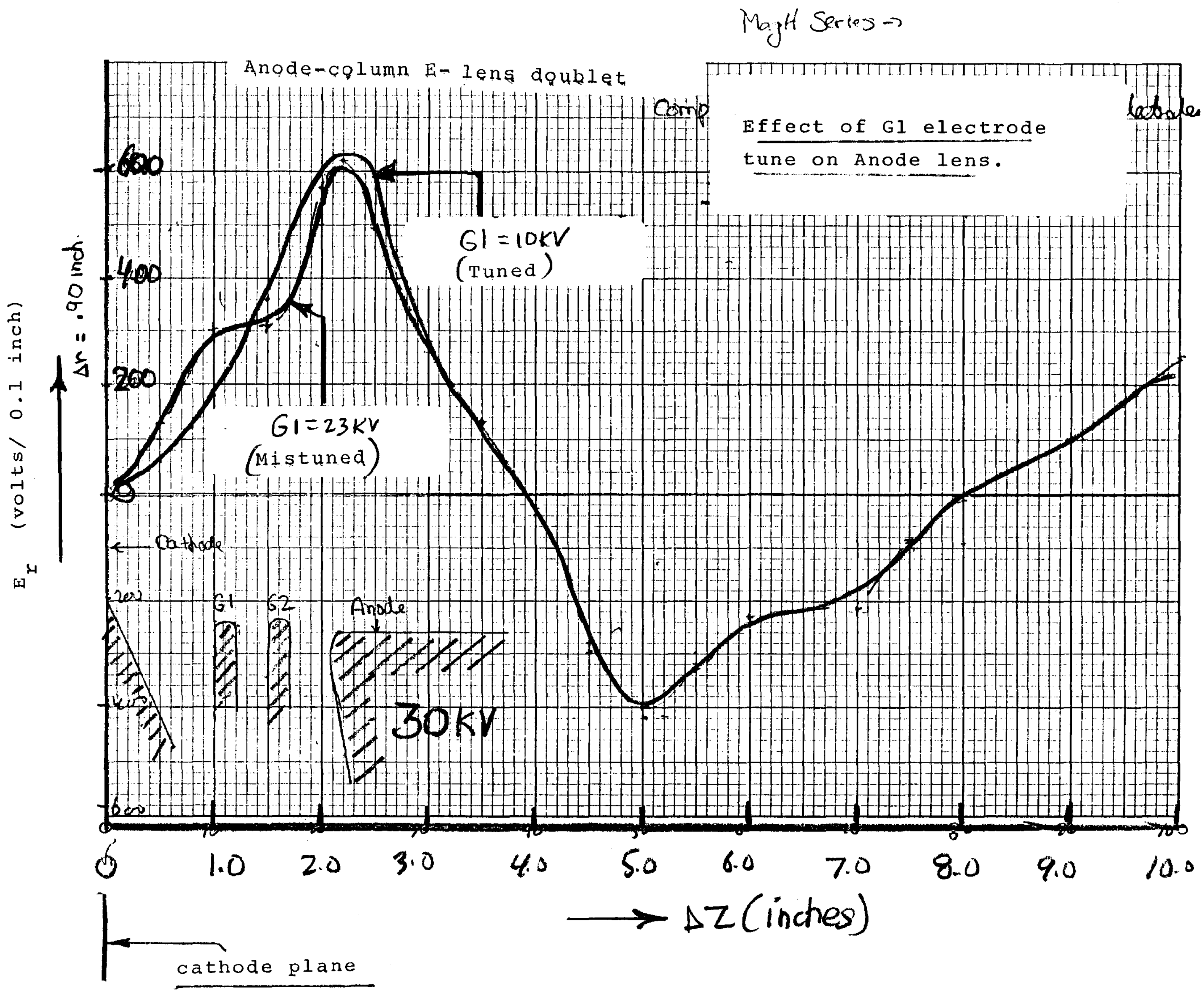

G1 Guard electrode control of gun emission uniformity
G2 = 23 KV
Anode = 30 KV
Bz=1000 gauss
16
14
12
10
8
6
4
2 %
0
5
10
15
20
25
30
-2
-4
-6
-8
-10%
G1 volts (kV)
$\left(\frac{\Delta J}{J}\right)_{avg}$
(Emission non-uniformity)

figure 2.



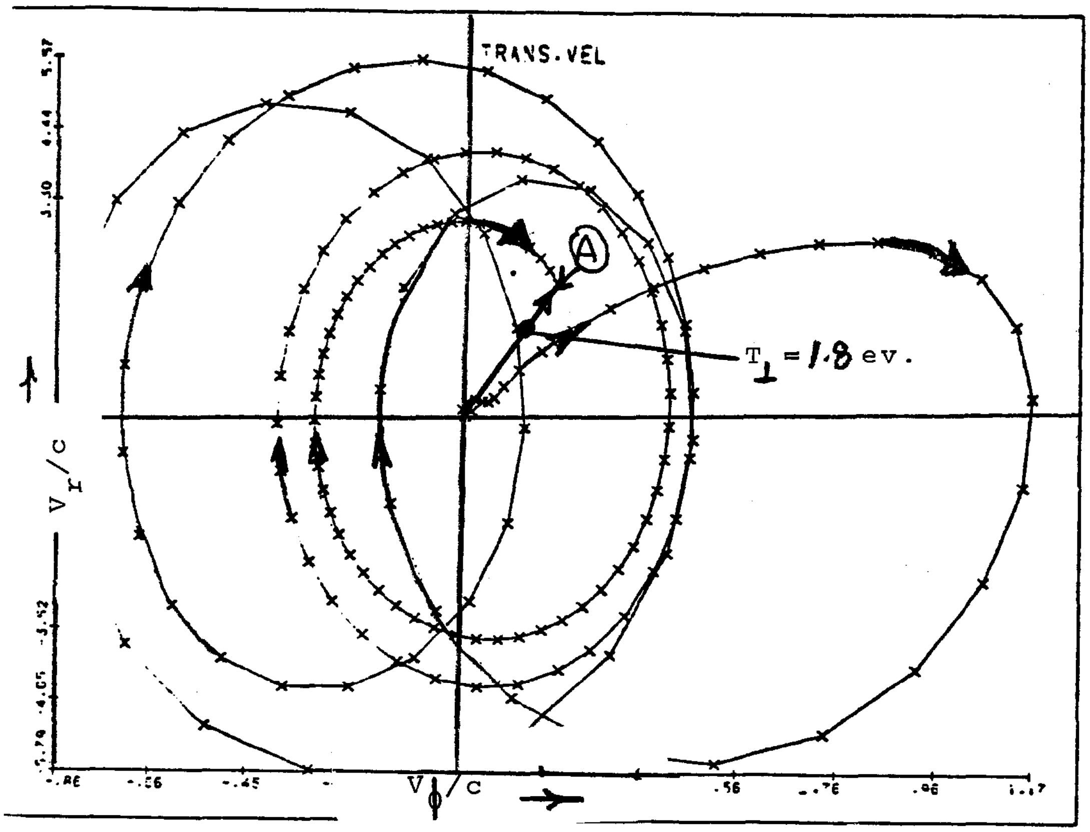
(I vs J series)
Accelerating column exit
E-lens effects.
longitudinal field
A -no gradient attenuation
B -6" attenuation section
$E_z(z)$
E_z (Kv/inch)
$\Delta z = 2$ inch
radial field
$E_r(z)$ at r = .90"
Radial field at column exit
$E_z(z)$
E_r (Kv/inch)
A
B
z
0 2 4 6 8 10 12 14
$\Delta Z \rightarrow$ (inches)
Seo. MAR 30/81.

Figure 3.



Majit Series →
Anode-column E- lens doublet
Comp
Effect of G1 electrode
tune on Anode lens.
G1 = 10KV
(Tuned)
G1 = 23KV
(Mistuned)
600
400
200
Δr = .90 inch
E_r (volts/ 0.1 inch)
Cathode
G1
G2
Anode
30KV
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
→ ΔZ (inches)
cathode plane

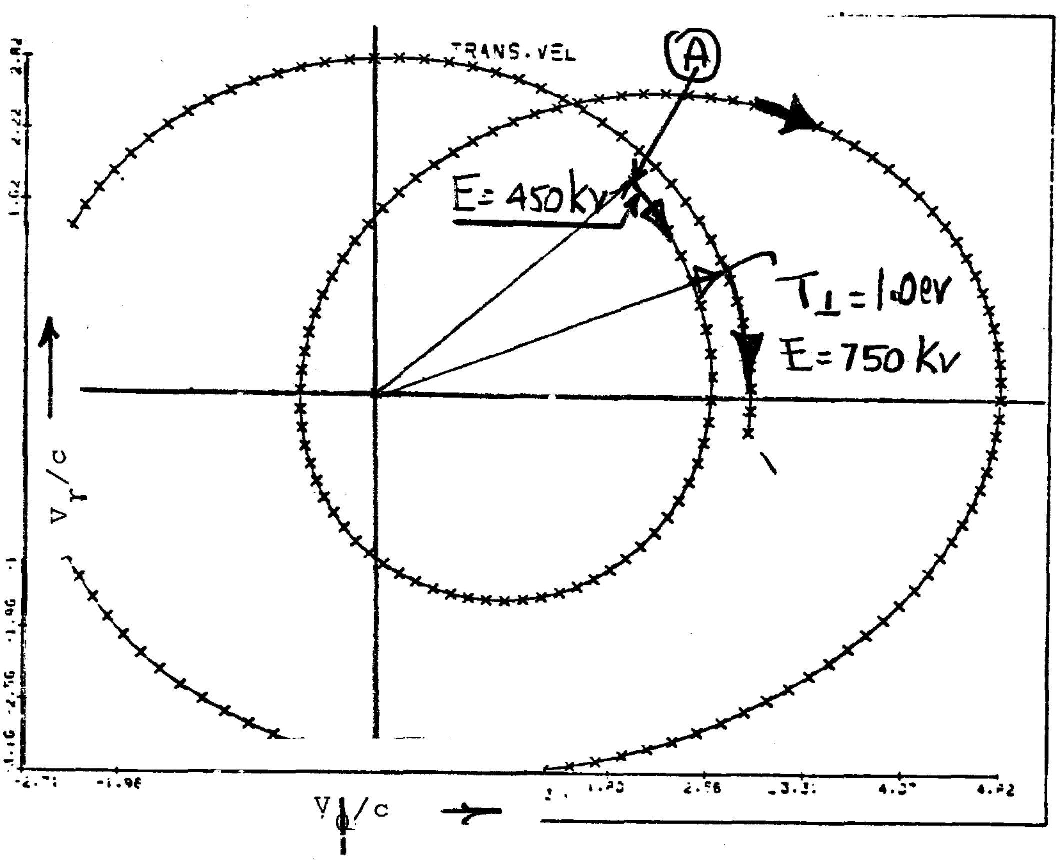
Figure 4.



Beam edge transverse temp. evolution through section I.

I=10 amps.

B_z=1000 gauss



Beam edge transverse temp. evolution through section II.

I=10 amps

B_z = 1000 gauss

Figure 5.